Spinulosa, as the more primitive. This opinion is also adopted by Hamann in "Bronn" and by Gregory in Ray Lankester's "Treatise on Zoology." Prof. MacBride alone, and, among late specialists in Asteroids, Perrier, have expressed the view that the Spinulosa are the more primitive of Asteroids. Is Prof. MacBride then not perhaps attaching somewhat too much value to his own opinion when he states that "all admit" the Spinulosa to be the most primitive group of Asteroids—with myself alone as an absurd exception ?

The question which group of Asteroids is the most primitive may not yet be definitely solved. If, however,—as *nearly* all admit—the Astropectinid forms are the most primitive, the conclusion is inevitably that the Brachiolaria, occurring—so far as evidence goes—only in the more specialised groups, the Spinulosa and Forcipulata, is a specialised larval form and its sucking disk a specialised, later acquired structure. Then this sucking disk is not homologous with the crinoid stalk, and its use in phylogenetic speculations is unjustified.

To Prof. MacBride's suggestion that my views would have some more value if I "had worked out with thoroughness the complete life-history of any Echinoderm," and to his protest against "the idea that those interested in Echinoderms agree with the over-estimate of the importance of trifling peculiarities in the structure of pedicellariæ in which Dr. Mortensen indulges" Dr. Bather has already kindly replied. In order not to make this belated reply too lengthy I shall then not take up these challenges at present. TH. MORTENSEN.

Zoological Museum, Copenhagen.
November 22.

Rotary Polarisation of Light.

IN the second edition of Dr. Tutton's monumental work on "Crystallography and Practical Crystal Measurement," a question of some interest to crystallographers and physicists is raised in an acute form by a footnote at the bottom of page 1082, which reads :—

> "Considerable confusion has been introduced into the subject of optical rotation by the fact that chemists, in their use of the polarimeter for the determination of the rotation of the plane of polarisation by optically active substances (chiefly liquids or solids in solution, but occasionally the solids themselves), have adopted a different convention, as regards the sign of the rotation, to that employed by physicists and crystallographers, who refer to the actual occurrence in the crystal itself. For instance, the right-handed quartz of the crystallographer actually rotates the plane of polarisation of light in the opposite direction to the so-called dextro-camphor of the chemist. The latter regards a rotation as right-handed or dextro when it appears clockwise to the observer looking through the eye-piece of the polarimeter. But the crystallographer regards himself as travelling with the beam of light, that is, as looking along the direction of propagation of the light: if the movement of the light in the crystal is like that of a right-handed screw, clockwise, the crystal is right-handed or dextro-gyratory, and if the light moves in left-handed screw fashion, anti-clockwise, the crystal is lævo-rotatory or left-handed. It is very important that this should be quite clear."

This question as to the precise meaning to be attached to the words "right-handed rotation" has been responsible for a certain amount of misunderstanding and confusion in text-books on mineralogy and physics for nearly a hundred years, and from Dr. Tutton's footnote it would appear that it is still unsettled.

Now the facts are simple. In 1813, the famous physicist Biot read a paper before the Institute of France[1] in which he described a number of experiments that he had made upon plates of rock-crystal cut perpendicularly to the axis of crystallisation. In carrying out this work Biot made the important discovery that there are two kinds of quartz—one in which the plane of polarisation is rotated to the right, while in the other the rotation is to the left. In carrying out these experiments Biot used a table polariscope, and adopting as a standard succession of colours that in which they ascend in Newton's scale, namely, red through yellow and green to blue, he found that a rotation of the analyser from left to right, that is in a clockwise direction, gave the standard succession for one kind of quartz, while an opposite rotation gave it for the other. The first rotation he spoke of as right-handed and the second, consequently, as left-handed. The experiments were subsequently carried out upon a considerable number of liquids and the convention of direction of rotation referred to was applied consistently.

In 1820, that is, seven years after Biot's discovery of right- and left-handed rotation of the plane of polarisation, Herschel read a paper before the Cambridge Philosophical Society[2] in which he announced his discovery that the direction of rotation of the plane of polarisation in quartz is indicated by the disposition of certain crystal faces.

Unfortunately, however, Herschel was not satisfied with Biot's convention, and he proposed to substitute for it one in which the observer was supposed to be looking along the beam of light in the direction in which the light was passing. While Biot, as it were, looked at an internally illuminated clock-face from the outside, Herschel preferred to look at it from the inside. Biot's right-handed thus became Herschel's left-handed rotation. Herschel, however, was consistent. He called the crystal which gave a right-handed rotation according to his convention, a right-hand crystal, and in giving the results of Biot's experiments on liquids, he changed the signs in order to bring them into accordance with his own convention. Thus according to Herschel cane sugar in solution rotates the plane of polarisation to the left.

Fig. 1 is a reproduction of the figure given in Herschel's original paper and reproduced in the article "Light" in the Encyclopædia Metropolitana (1830). In this article it is stated that the figure "represents a right-hand crystal." It is important to note here that in practically all modern books this figure illustrates a left-hand [twin] crystal. The confusion resulting from Herschel's attempt to substitute his convention for that of Biot was soon apparent.

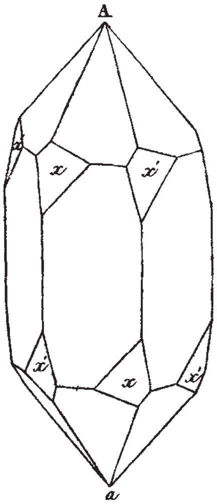

FIG. 1.—A right-hand crystal (Herschel).

In 1843 a book entitled "Lectures on Polarised Light delivered before the Pharmaceutical Society of Great Britain" appeared. This admirable little book of some hundred pages was written by Dr. Pereira. Now Dr. Pereira was evidently alive to the danger of confusion arising from the existence of contradictory conventions such as those of Biot and Herschel, because, on page 86, he writes :—

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[1] "Mémoires de la classe des Sciences mathématiques et physiques de l'Institut Impérial de France (Année 1812),".Pt. I. pp. 263-4.

[2] Trans. Cam. Phil. Soc., vol. i. p. 43 (1821).

"There are two varieties or kinds of circularly polarised light which have been respectively distinguished by the names of dextrogyrate or right-handed, and lævogyrate or left-handed.

"In one of these the vibrations are formed in an opposite direction to those in the other. Unfortunately, however, writers are not agreed on the application of these terms ; and thus the polarisation, called, by Biot, right-handed, is termed, by Herschel, left-handed, and vice versa. There is, however, no difference as to the facts, but merely as to their designation. If, on turning the analysing prism or tourmaline *from left to right*, the colours descend in Newton's scale, that is, succeed each other in this order—*red, orange, yellow, green, blue, indigo,* and *violet,* Biot designates the polarisation as *right-handed,* or +, or ↗; whereas if they descend in the scale by turning the analyser *from right to left,* he terms it *left-handed,* or −, or ↖. Sir John Herschel, on the other hand, supposes the observer to look in the direction of the ray's motion. Let the reader, he observes, 'take a common corkscrew, and holding it *with the head towards him,* let him use it in the usual manner, as if to penetrate a cork. The head will then turn the same way with the plane of polarisation as a ray in its progress *from* the spectator through a *right-handed* crystal may be conceived to do. If the thread of the corkscrew were reversed, or what is termed a *left-handed thread,* then the motion of the head, as the instrument advanced, would represent that of the plane of polarisation in a left-handed specimen of rock-crystal.'

"I shall adopt Biot's nomenclature, and designate the polarisation right-handed or left-handed according as we have to turn the analysing prism to the right or to the left to obtain the colours in the descending order."

We have in these paragraphs a very clear and unambiguous statement of the two conventions. Biot's is finally adopted and used consistently throughout the book. It will be noted, however, that Pereira speaks of colours which succeed each other in the order, red, orange, yellow, etc., as descending in Newton's scale.

A second and greatly enlarged edition of Pereira's book, edited by the Reverend Baden Powell, appeared in 1854, after the author's death. In this edition the above paragraphs remain substantially the same, except that the words "the colours descend in Newton's scale, that is, succeed each other in this order, red, orange, yellow, green, blue, indigo, and violet," in the first edition, are replaced by these words in the second edition (see p. 253)—"The colours *descend* in the order of Newton's scale—that is, succeed each other in the order of the colours of their plates, reckoning from the central black as the highest point."

It will be noticed that the enumeration of the colours, red, orange, yellow, etc., has been replaced by the words "succeed each other in the order of the colours of their plates, reckoning from the central black as the highest point," so that we must seek further for information as to the meaning of the words "descend in the order of Newton's scale" as used in the second edition. And turning to page 256, we read :—

"Thus, suppose we turn the analyser right-handed, that is, as we screw up, the colours succeed each other, with a certain thickness of the crystal, in this order—*red, orange, yellow, green, purple, red* again, and so on, in the ascending order of Newton's scale, on the colours of thin plates, before given."

So that in the second and first editions, the word "descend" has contradictory and opposite meanings. In the first edition it refers to colours succeeding one another in the order, red, yellow, green, and blue, whereas in the second edition the word "ascending" is used to denote the same order of colours. The result is that while Biot's convention was given clearly and correctly in the first edition, and used consistently, that given as Biot's convention in the second edition is, unfortunately, not Biot's but Herschel's convention, but both are used, with the result that the student gets hopelessly puzzled.

In Dr. Tutton's book, in spite of the warning in the footnote quoted, the first and also the second editions have apparently been written consistently with the Biot convention. In the first edition, for example, at pp. 802-803 and in the second edition at pp. 1082-1083, it is stated that "a slight rotation of the analyser from the position for the violet transition tint, to the right (clockwise) or left (anti-clockwise) according as the crystal is right-handed or left-handed, causes the colour to change to red (first order). On the other hand, a rotation of the analyser contrary to the rotary character of the plates causes the violet transition tint to change to blue or green (second order)." This statement, it will be seen upon consideration, can only be true of the right- and left-handed crystals shown by Figs. 344 and 345 of the first edition (here reproduced in Fig. 2) and Figs. 311-312 of the second edition, upon Biot's convention. Upon Herschel's convention the words "right (clockwise)" and "left (anti-clockwise)" should be transposed in the above quotation.

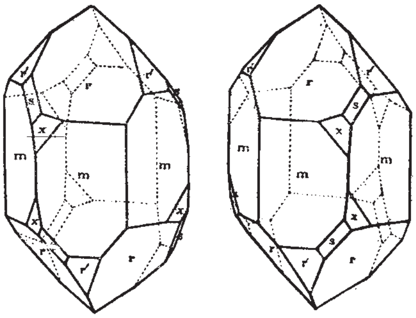

Fig 344.—Left-Handed Crystal of Quartz.

Fig. 345.—Right-Handed Crystal of Quartz.

Fig. 2.

Any attempt to revive Herschel's convention should, I think, be resisted. Simple experimental facts should be capable of description in clear and unambiguous language, and this, as has been shown, is not likely to be achieved so long as two conventions, in such a simple matter, are tolerated. The fact that Herschel himself brought his convention into line with crystallographic nomenclature by calling what is now universally accepted as a right-hand crystal, a left-hand crystal, has been overlooked. The crystallographic conceptions of right- and left-handed crystals are not likely to be changed now, so that the adoption of the Herschel convention by any writer will, or should, necessitate the definite statement that according to this convention a right-hand crystal is made up of left-hand quartz. Dana, it is true, in his "System of Mineralogy" gives Herschel's convention, but he accepts at the same time the usual definition of right- and left-hand crystals, so that a right-hand crystal, according to him, is left-hand optically. It should be remembered, however, that the last edition of Dana appeared thirty years ago. Later writers such as Miers, Johannsen, Duparc, and Pearce, and many others, have not, however, followed Dana—a crystal right-hand crystallographically, is also right-hand optically with them. F. CHESHIRE.

Imperial College of Science,
South Kensington,
October 27.

I AM much indebted to Prof. Cheshire for stating so clearly the historic incidence of the confusion which has arisen in regard to the designation of the two types of optical rotation, as to which shall be called right-handed and which left-handed, due largely to the reversal of Biot's convention by Sir John Herschel, and to the similar reversion in the second edition of Dr. Pereira's book. Other investigators and experimenters have also adopted the reversal, for instance, Sir William Spottiswoode at the time he was president of the Royal Society, for on pp. 47-48 of his book, "Polarisation of Light," we read: "A right-handed ray is one in which, to a person looking in the direction in which the light is moving, the plane of vibration appears turned in the same sense as the hands of a watch." Moreover, if instead of using the polariscope as a table instrument one projects the phenomena on the screen, the picture there displayed is reversed exactly like a lantern slide, which has to be inverted in the lantern (the two spots in front at the top being brought to the bottom at the back), in order to get an upright picture on the screen. Thus, for example, in the mica-sector experiment of the late Prof. S. P. Thompson (pp. 1103-1104 of the second edition of my "Crystallography and Practical Crystal Measurement"), the black cross moves on the screen one sector to the left for a right-handed quartz crystal and to the right for a left-handed one; whereas on looking through the same instrument used as a table polariscope the movement is to the right for a right-handed crystal, in accordance with the Biot convention.

It is thus important to know the exact conditions of the experiment whenever the question of the correct discrimination of right- or left-handedness in the optical rotation of crystals is being dealt with. Further, the safest course, in the case of quartz, is to cut the section-plate to be used to afford the definite decision from a crystal which is clearly a single individual, and not a twin, showing the little *s* and *x* faces unmistakably, and this course was pursued by me in the preparation of my "Crystallography." As most in accordance with current practice (that of von Groth and Pockels, for example), and in rightful deference to Biot, the discoverer of the two optically active kinds of quartz, Biot's convention was used, in both editions of the book, a course which it is satisfactory to learn meets with the approval of Prof. Cheshire. The apparent opposite, on p. 1101, lines 7-8, is due to this being a projection experiment, the observer looking towards the screen along with the light rays; the direction here, however, really does not matter, as only the colour of the centre of the field is being referred to; even here, perhaps, it would be better in any future edition (they were not present in the first edition) to omit the words "from the point of view of the observer looking in the same direction as the light is being propagated," the text then conforming clearly with the Biot convention. On p. 1083, where a table experiment is being referred to, and the conditions are otherwise similar to those in the centre of the field in the case just referred to, there is no ambiguity, the Biot convention being clearly followed.

It was felt desirable to direct attention to the confusion which has so obviously arisen, and this was done in the footnote to p. 1082. Emphasis was attempted to be laid on the fact that, after all, the phenomena are due to the passage of the ray through the helical structure of the crystal, now so happily confirmed by Sir William Bragg's X-ray analysis of quartz, and that the observer does well to imagine himself travelling with the rays through the screw, in order to appreciate the cause of the rotation of the plane of polarisation or vibration of the light rays. The particular screw type, right- or left-handed, is the same, however, whether we regard the screw from one end of it or the other, whether we look along with or against the light stream; otherwise it would matter which side up the quartz plate were arranged, that is, which side were placed the nearer to any particular one of the nicols. But the optical effect, the rotation of the plane of polarisation or of vibration of the light rays, is, of course, what matters and what is so clearly different for the two different types of quartz helices, and it was my intention to retain and use the Biot convention for its directional (right- or left-handed) designation. The footnote in question is not sufficiently explicit, and must be amended in any future edition. Prof. Cheshire and the writer are, however, quite agreed on the facts, and that this Biot convention shall be the one employed, and I am grateful to Prof. Cheshire and to the editor of NATURE for affording me the opportunity of stating this. A. E. H. TUTTON.

Space-Time Geodesics.

IN his letter in NATURE of November 25, replying to mine which appeared in NATURE of October 28, Prof. Piaggio points out that the equations of Space-Time geodesics may be deduced by other methods than those of the calculus of variations, and suggests that, in some such way, it is possible to get over the difficulties to which I directed attention.

My criticism, however, was directed, not merely against the definition of Space-Time geodesics as *minimum lines*, but against all seeming definitions of them which start from ideas of measurement as a fundamental basis.

I must, however, in passing, warn my readers against what at first sight looks like a suggestion, though I have no doubt that it was not so intended by Prof. Piaggio, that Space-Time geodesics might be defined in terms of "*the osculating plane*."

If there were any strict analogy with the case of geodesics on surfaces in ordinary three-dimensional geometry, such an "*osculating plane*" would (apart from a line of intersection) have to lie in some mysterious region outside our Space-Time continuum altogether. Prof. Piaggio, however, I have no doubt, wishes to lay stress upon the equations he obtains.

I was of course aware that the *equations* of Space-Time geodesics could be arrived at by various analytical devices; but how much better off does this leave us? Consider, for example, the simple Space-Time analysis as given by Minkowski and see what it implies.

In the first place, it implies a set of co-ordinate axes x, y, z, and t, which are themselves *geodesics*.

How are these particular geodesics to be defined?

They cannot be defined as minimum lines, for they are not minimum lines; and we cannot use our co-ordinate system to define them, since we are now contemplating how the co-ordinate system can be set up.